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# Stock assessment of a large marine gastropod (*Strombus gigas*) using randomized and stratified towed-diver censusing

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The queen conch (*Strombus gigas*) constitutes a small-scale, shallow-water fisheries throughout the Caribbean zoogeographic province. Many of these fisheries have been closed or restricted because of severe overfishing. This study was designed to determine stock abundance in Florida waters, where queen conch are protected, and to monitor stock recovery. The study area constituted approximately $2.4 \times 10^5$ hectares, extending over 200 km from Virginia Key to Boca Grande Key, and from the nearshore intertidal to 20-m depths approximately 10 km offshore. It was subdivided into 11 equal areas, surveyed photometrically, and mapped by bottom habitat type. Each habitat was sampled in proportion to its coverage on each map. A sampling program stratified by season, map, and habitat was devised. Transects were surveyed by towing two divers behind a boat simultaneously for 30 min. They counted all conch within a swath 6 m wide and approximately 2 km long. During the 13-season study period, 1121 transects were completed, covering 1423 hectares. Conch densities varied greatly among transects, because of the spatial heterogeneity of this mobile animal, causing high variances and non-parametric distribution of the data. Seasonal average density of adults varied from 0.04 to 1.1 conch/ha (average 0.3). A comparison of density values for Season 1 and Season 13 showed no statistically significant change in the density of total conch or of adults, although adult conch appear to have aggregated in the reef habitat. Based on overall average density for Season 13, we estimate there are only $2 \times 10^5$ adults in the Florida Keys. Therefore, it is not appropriate to drop the protected status of conch at this time.

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## Introduction

The queen conch (*Strombus gigas*) is distributed throughout the shallow waters of the Caribbean, Florida, and the Bahamas, and in areas as far north as Bermuda. A short-lived planktonic larval stage is followed by a juvenile interval typically lasting three years (Berg and Olsen, 1989), although shorter durations for isolated aggregations have been reported (Alcolado, 1976; Glazer and Berg, 1992). Sexual maturity is characterized by the cessation of growth and the formation of the familiar flared-lip.

Conch have been fished historically for both the meat and the shell trade. With the advent of freezer ships and air cargo, extensive import markets developed in the United States of America and elsewhere. To meet export demands, collecting in ever-deeper waters occurred throughout the region, severely depleting natural populations (Berg and Olsen, 1989).

Management measures and the demise of numerous island conch fisheries have been documented repeatedly (Brownell and Stevely, 1981; Wells *et al.*, 1983; Berg and Olsen, 1989). The most effective way of protecting the species and allowing the population to recover appears to be a total ban on all collecting of live queen conch (Munoz *et al.*, 1987). In Florida, the recreational and commercial fishery was closed in June 1985, when conch became protected by Chapter 46-16 of the Florida Administrative Code. The re-opening of the fishery for queen conch in Florida is dependent upon the presence

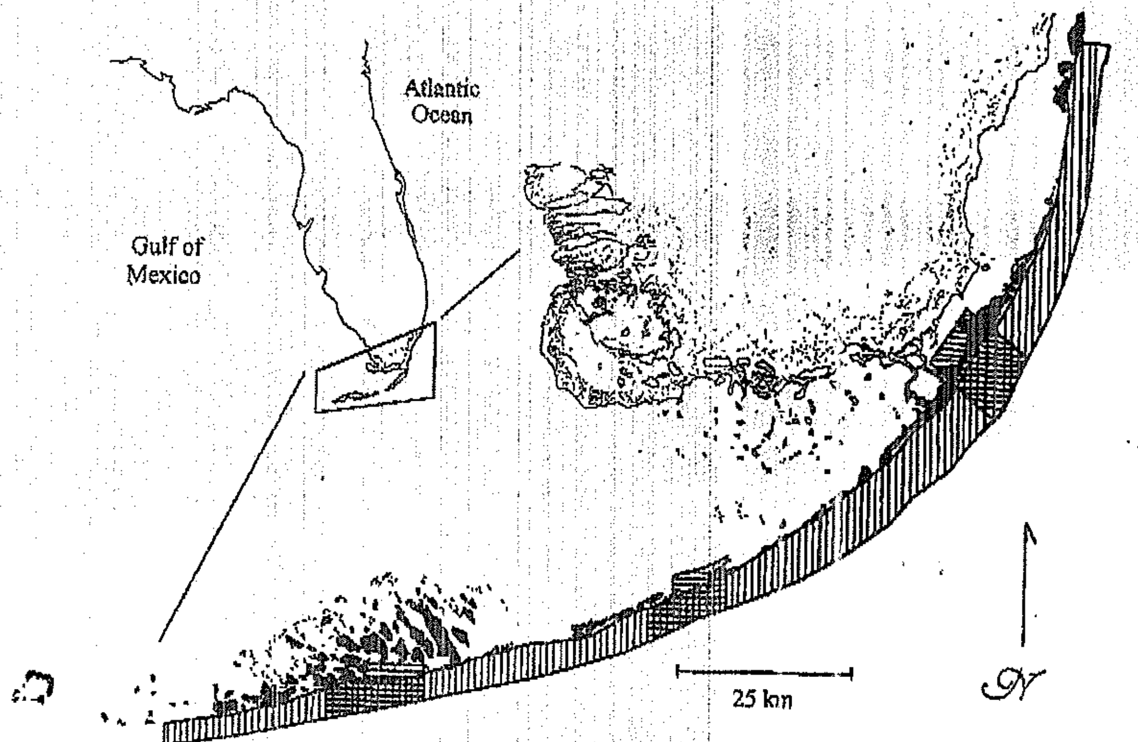


Figure 1. Location of stock assessment and stock monitoring surveys. Vertical lines represent areas surveyed during stock assessment and Season 13. Horizontal lines represent locations surveyed during the stock monitoring program and Season 13. Cross hatched areas were surveyed throughout the study.

of sufficient numbers of animals to maintain a sustainable yield.

In 1987 the Florida Department of Environmental Protection initiated a program to determine the distribution and abundance of conch in Florida's waters (Berg and Glazer, 1991). Similar studies were completed in the Virgin Islands (Wood and Olsen, 1983) and the Bahamas (Smith and van Nierop, 1984). In addition, a research program was devised to monitor changes in abundance and distribution in order to develop a fisheries management plan if the population recovered sufficiently.

For management purposes, queen conch in Florida waters were considered to be a single fisheries stock. Electrophoretic analysis of conchs from aggregations distributed over the length of the Florida Keys indicated that they belonged to a single genetic stock (Campton *et al.*, 1992), but whether it is a closed, self-sustaining stock or receives recruits from the Caribbean via the larval planktonic stage has not been determined. Extensive gene flow has been described for this species (Mitton *et al.*, 1989), so recruitment from other areas and the rebuilding of the Florida stock was expected.

## Methods

### Stock assessment

In Florida, queen conch are found almost exclusively in the shallow waters of the Florida Keys. Our study area extended from Virginia Key (25°45′N, 80°10′W), southwest to Boca Grande Key (24°26′N, 82°00′W) (Fig. 1). The total survey area constituted approximately 241 700 hectares. Because the entire area could not be surveyed or monitored continually, a stratified sampling program was devised. First, sampling was divided into the four calendar seasons (spring, summer, fall, and winter) to account for seasonal migratory behavior and burying of conch (Randall, 1964; Hesse, 1979; Weil and Laughlin, 1984; Coulston *et al.*, 1987; Stoner *et al.*, 1988; Stoner, 1989). A one-year sampling program began in spring 1987 and continued for four seasons through winter 1988. A follow-up program was completed in spring 1990.

Second, sampling of the area oceanside from Virginia Key to Key West was divided into 10 survey maps according to Marszalek's (1981) maps of the marine habitats and ecosystems of the Florida Reef Tract.

These maps were updated and corrected using more recent aerial photographs and were digitized by Florida Department of Environmental Protection's remote-sensing laboratory. One additional survey map was drafted from navigational charts for the area extending from Key West to Boca Grande Key, but no habitat designations were available.

Third, sampling on each survey map was divided into four main marine habitats (reef, bedrock, sediment, and seagrass) by Marszalek (1981). A fifth habitat, "blue-water", was added which encompassed those areas in <20 m of water that lacked habitat designations on Marszalek's maps. The number of hectares covered by each habitat and the percentage of coverage of each were determined from the corrected maps. A total of 10 survey transects were scheduled per season for each of the 11 survey maps. The number of transects allocated to each of the five habitats was proportional to its relative coverage on each map, with each habitat surveyed at least once.

Each map was divided into a grid based on a 30-sec coordinates of latitude and longitude that were each numbered sequentially. Two random numbers provided by x and y coordinates for each transect. These numbers were chosen using the STATGRAPHICS 2.6 program for uniformly distributed random number generation (STSC, Inc., 1986). Grid positions were translated into actual field locations using sightings of landmarks, water depth, bottom habitat, and LORAN coordinates. Transects originated in the area designated on the grid and proceeded in the direction that would maintain safe working conditions and keep the transect over the chosen habitat. In sampling each transect, two SCUBA divers were towed behind a boat for 30 min at approximately 60 m/min. Using a dive sled, they maintained a distance approximately 1.5 m above the bottom so that each was able to visually scan a strip 3 m wide. Wider transect widths were discounted because of fluctuating water turbidity within individual transects and because trial transects at the onset of the study indicated that all conch in a 3-m swath could be counted reliably. In excessively turbid waters the width of the strip was reduced. The length of the strip varied according to the distance covered during the 30-min recording period and was calculated from latitude and longitude positions obtained using a Raynav-550 Loran C Navigator and the Marine Navigation Program of a Texas Instruments TI 59 calculator.

Each diver counted the number of juvenile and adult *S. gigas* occurring within his strip. Adults were defined as those animals having a flared shell-lip. Counts of animals were recorded on the dive sleds at 10-min intervals and transcribed onto data sheets at the end of each tow. Observations of both divers were combined into a single transect record. All data were entered into a computer for analyses. Average density ±1 s.d. are presented, although the data are non parametrically distributed and median and modal values are almost always zero. Differences among samples were tested using the Kruskal-Wallis and Mann-Whitney tests of the STATGRAPHICS 4.0 program (STSC, Inc., 1989). Estimates of population abundance ($\tau$) were derived using methods of Mendenhall *et al.* (1971, p. 38). Empirical Bayes estimates of population density were derived following Johnson (1989).

## Stock monitoring

A stock monitoring program began in spring 1988 and continuing through winter 1990 used techniques identical to those of the stock assessment program, but included only areas covered by Marszalek Maps 3, 6, and 9 (Fig. 1). These areas were chosen to represent the entire region for the following reasons: (1) they were located in the upper, middle, and lower Florida Keys, respectively; these areas differ in the amount of water flowing over them from Florida Bay and so have different community structures (Jaap, 1984; Shinn, 1989); (2) their values for mean conch/ha from the first year's stock assessment program ranked them in the middle (4th, 6th, and 7th when ranked from lowest values) of the 11 survey maps (Table 1); and (3) they were easy areas to work. A total of 25 transects were scheduled for each map per season, instead of the 10 transects used in the stock assessment program. The area covered by the survey was expanded to include up to 1.6 km into Florida Bay and the channels between the islands (Fig. 1). This area was designated as "Bay" habitat and the number of transects over each of the six habitats was recalculated to be proportional to the percentage of coverage by each habitat type. Data were analyzed as in the stock assessment program.

# Results

A total of 424 transects were completed from 16 March 1987 to 6 April 1988, designated as the 1987 sampling year. Not all maps were surveyed equally (Table 1) because of unfavorable weather and sea conditions. Total area surveyed was 544 ha, comprising 0.23% of the total area. Using data stratified by map, the overall average density of conch was 2.4 conch/ha (Table 1). Using data stratified by season, the average density of conch was also 2.4 conch/ha (Table 2, Fig. 2), mainly due to a single transect over a herd of juveniles where the density was 610 conch/ha. This value introduced a large variance into the statistical analyses. Density of adult conch did not increase; mean density for the year was only 0.47 adult conch/ha (Table 2). Kruskal-Wallis

Table 1. Results of 1987 conch stock assessment program. Calculated values are: average density (conch/ha), standard deviation (SD), coefficient of variation (CV), and estimated population abundance ($\times 10^3$). Range is from 0 to maximum density observed.

| Map | Tows | Total | Sampled Area | Density | Range | SD | CV | Abundance ($\times 10^3$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 40 | 204 | 50.97 | 4.20 | 106.20 | 17.19 | 409 | 82.30 |
| 2 | 40 | 369 | 51.61 | 6.74 | 121.03 | 21.93 | 325 | 156.80 |
| 3 | 40 | 27 | 52.32 | 0.42 | 11.40 | 1.82 | 430 | 8.90 |
| 4 | 40 | 7 | 50.45 | 0.16 | 3.44 | 0.70 | 444 | 4.00 |
| 5 | 37 | 11 | 46.13 | 0.27 | 2.96 | 0.66 | 242 | 5.10 |
| 6 | 40 | 75 | 51.04 | 1.57 | 48.59 | 7.66 | 488 | 36.40 |
| 7 | 40 | 624 | 53.95 | 7.88 | 305.03 | 48.19 | 612 | 163.90 |
| 8 | 40 | 108 | 52.26 | 1.96 | 29.35 | 4.79 | 244 | 44.90 |
| 9 | 36 | 80 | 45.68 | 1.70 | 23.42 | 4.89 | 287 | 39.30 |
| 10 | 34 | 33 | 46.88 | 0.67 | 6.98 | 1.39 | 207 | 15.40 |
| 11 | 33 | 6 | 42.50 | 0.14 | 1.06 | 0.31 | 221 | 2.90 |
| Overall | 420 | 1544 | 543.79 | 2.41 | 305.03 | 17.42 | 724 | 581.70 |

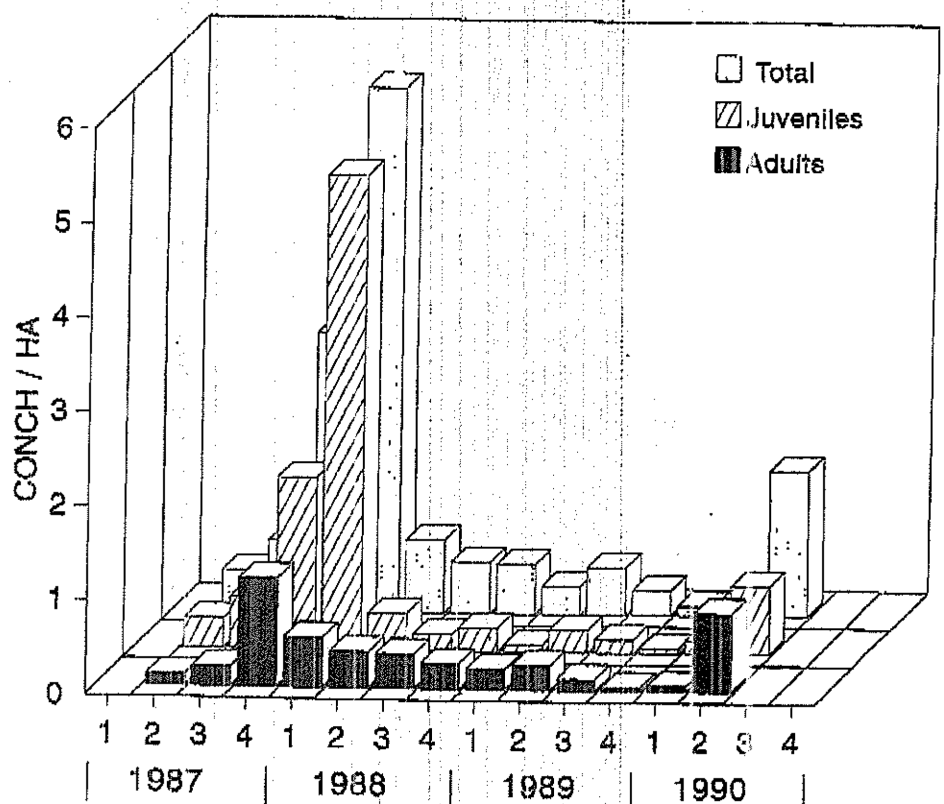


Figure 2. Average density (conch/ha) of adult conch, juvenile conch, and total conch in the Florida Keys. Quarter-year designations correspond to Seasons 1 to 13 of Table 1, starting with Season 1 in the second quarter of 1987 and continuing to Season 13 in the second quarter of 1990.

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Table 2. Density (conch/ha), standard deviation (SD), and coefficient of variation (CV) of *Strombus gigas* for each season (1987–1990). Mean and overall values for each season are based upon the entire data set, not the four seasonal averages.

| Season | | # Tows | Area sampled | # Animals | | | Adults | | | Juveniles | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Adults | Juv | Total | Density | SD | CV | Density | SD | CV | Density | SD | CV |
| | 1987 | | | | | | | | | | | | | | |
| | 1 | 110 | 126.4 | 14 | 40 | 54 | 0.12 | 0.40 | 337 | 0.31 | 0.69 | 221 | 0.43 | 0.91 | 213 |
| | 2 | 110 | 133.9 | 29 | 74 | 103 | 0.21 | 1.30 | 632 | 0.54 | 2.09 | 384 | 0.75 | 2.99 | 399 |
| | 3 | 94 | 130.2 | 144 | 212 | 356 | 1.14 | 5.46 | 479 | 1.82 | 11.03 | 607 | 2.96 | 13.03 | 440 |
| | 4 | 110 | 153.3 | 86 | 945 | 1031 | 0.53 | 3.00 | 568 | 5.03 | 30.85 | 613 | 5.56 | 31.50 | 567 |
| Overall Mean | | 424 | 543.8 | 273 | 1271 | 1544 | 0.47 | 3.09 | 653 | 1.93 | 16.70 | 865 | 2.40 | 17.38 | 723 |
| | 1988 | | | | | | | | | | | | | | |
| | 5 | 75 | 105.3 | 44 | 44 | 88 | 0.38 | 1.44 | 375 | 0.39 | 1.62 | 414 | 0.77 | 3.01 | 388 |
| | 6 | 75 | 103.5 | 34 | 19 | 53 | 0.37 | 1.86 | 509 | 0.18 | 1.01 | 571 | 0.54 | 2.46 | 452 |
| | 7 | 66 | 83.7 | 26 | 21 | 47 | 0.28 | 1.72 | 625 | 0.25 | 0.80 | 324 | 0.52 | 1.94 | 372 |
| | 8 | 75 | 86.0 | 16 | 7 | 23 | 0.22 | 1.31 | 602 | 0.08 | 0.33 | 401 | 0.30 | 1.37 | 459 |
| Overall Mean | | 291 | 378.5 | 120 | 91 | 211 | 0.31 | 1.60 | 512 | 0.22 | 1.06 | 475 | 0.54 | 2.29 | 428 |
| | 1989 | | | | | | | | | | | | | | |
| | 9 | 75 | 93.9 | 25 | 22 | 47 | 0.26 | 0.89 | 341 | 0.24 | 0.94 | 393 | 0.50 | 1.68 | 336 |
| | 10 | 75 | 96.1 | 13 | 14 | 27 | 0.12 | 0.39 | 318 | 0.14 | 0.42 | 305 | 0.26 | 0.68 | 260 |
| | 11 | 71 | 89.6 | 3 | 5 | 8 | 0.04 | 0.22 | 508 | 0.06 | 0.25 | 446 | 0.10 | 0.33 | 328 |
| | 12 | 75 | 86.4 | 4 | 12 | 16 | 0.06 | 0.24 | 429 | 0.14 | 0.45 | 320 | 0.20 | 0.50 | 251 |
| Overall Mean | | 296 | 366.0 | 45 | 53 | 98 | 0.12 | 0.53 | 429 | 0.15 | 0.58 | 402 | 0.26 | 0.97 | 364 |
| | 1990 | | | | | | | | | | | | | | |
| | 13 | 110 | 135.1 | 113 | 88 | 201 | 0.82 | 3.56 | 433 | 0.72 | 5.95 | 630 | 1.54 | 9.25 | 601 |

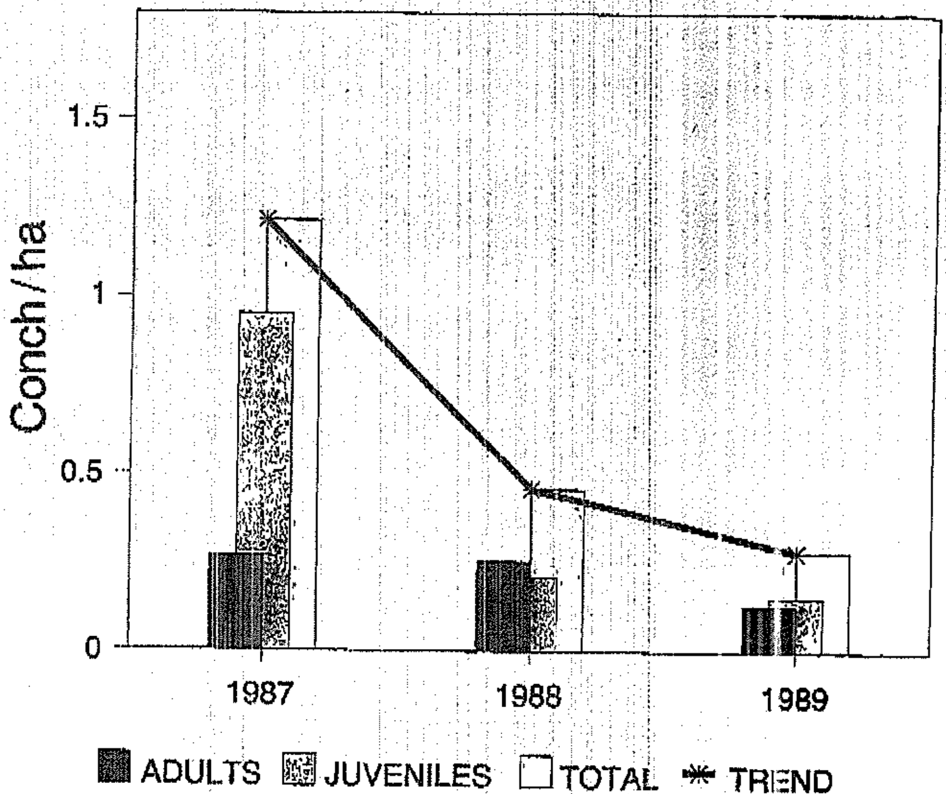


Figure 3. Annual average density (conch/ha) of adult conch, juvenile conch and total conch in the Florida Keys based on comparable data from Maps, 3, 6, and 9 only.

analyses indicated no statistically significant differences in conch density either spatially, seasonally, or by habitat.

Total abundance was calculated from the first year's data in three ways. First, by using the sum of the average values of conch/ha calculated for each map multiplied by the total area of ocean bottom <20 m depth of that map (567 645 conchs). Second, by using the sum of the average value of conch/ha calculated for each habitat multiplied by the area of each habitat across Maps 1 to 10, abundance for those maps was estimated to be 422 048 conchs. Map 11 was excluded in this estimate because no habitat designations were available. Overall total abundance was 461 298 conchs, which represents a 9.3% increase to account for the area of Map 11. Third, by using the sum of the average value of conch/ha calculated for each season multiplied by the total area of the study region, and the sum divided by four, overall estimated abundance was 585 757 conchs. Because adults constituted 17.7% of the observed animals, we estimated their total abundance to be 103 679 conchs.

During the second and third years of the study (Seasons 5 to 12, Table 2) the stock monitoring program focused on Maps 3, 6, and 9 only. Because more transects were surveyed on each map than in the previous year, percent coverage doubled, to 0.46% in the 1988 sampling year and 0.44% in 1989. During those two years there was no significant change in the mean density of total conch per season, adult conch per season, or juvenile conch per season (Table 2, Fig. 2). In order to compare the 1987 stock assessment data with the 1988 and 1989 stock monitoring data, we used only Maps 3, 6, and 9 from the 1987 data and we deleted data from the Bay habitat that we surveyed only in the later years. Although there appears to be a trend of decreasing density (Fig. 3). Kruskal-Wallis analysis of the data shows no significant difference among years. Adult density, in particular, did not change.

In Season 13 (Spring of 1990) both a Map 1 to 11 and a Map 3, 6, 9 sampling program were completed to provide stock assessment data using methods identical to those used in Season 1 (Table 3). When values for Season 1 and Season 13 were sorted by habitat (Maps 1 to 10 only) and compared using the Mann-Whitney two-tailed test for probabilities of difference, there was no significant difference between the seasons in total

Table 3. Comparison of *Strombus gigas* abundance between Season 1 and Season 13, with data stratified by habitat. Data from 100 tows in Maps 1 to 10 during each season. Total values based on entire data set, not averages of each habitat.

| | Season 1 | | | Season 13 | | |
|---|---|---|---|---|---|---|
| Habitat | Area sampled | Density | Abundance ($\times10^3$) | Area sampled | Density | Abundance ($\times10^3$) |
| ADULTS | | | | | | |
| Reef | 11.6 | 0.00 | 0.0 | 12.7 | 3.84 | 85.3 |
| Bedrock | 11.4 | 0.38 | 9.8 | 14.5 | 1.75 | 44.9 |
| Sediment | 28.8 | 0.07 | 5.0 | 31.9 | 0.28 | 19.7 |
| Seagrass | 50.8 | 0.11 | 10.8 | 52.5 | 0.50 | 50.1 |
| Bluewater | 10.3 | 0.23 | 0.8 | 12.0 | 0.09 | 0.3 |
| Total | 114.3 | 0.13 | 28.6 | 123.6 | 0.91 | 200.6 |
| JUVENILES | | | | | | |
| Reef | 11.6 | 0.12 | 2.6 | 12.7 | 6.24 | 138.5 |
| Bedrock | 11.4 | 0.87 | 22.3 | 14.5 | 0.41 | 10.6 |
| Sediment | 28.8 | 0.34 | 23.8 | 31.9 | 0.19 | 12.9 |
| Seagrass | 50.8 | 0.25 | 25.0 | 52.5 | 0.00 | 0.0 |
| Bluewater | 10.3 | 0.30 | 1.0 | 12.0 | 0.08 | 0.3 |
| Total | 114.3 | 0.33 | 73.0 | 123.6 | 0.79 | 174.3 |
| TOTAL | | | | | | |
| Reef | 11.6 | 0.12 | 2.6 | 12.7 | 10.08 | 223.8 |
| Bedrock | 11.4 | 1.25 | 32.1 | 14.5 | 2.16 | 55.5 |
| Sediment | 28.8 | 0.41 | 28.7 | 31.9 | 0.47 | 32.7 |
| Seagrass | 50.8 | 0.36 | 35.8 | 52.5 | 0.50 | 50.1 |
| Bluewater | 10.3 | 0.53 | 1.8 | 12.0 | 0.17 | 0.6 |
| Total | 114.3 | 0.46 | 101.7 | 123.6 | 1.70 | 374.8 |

density of conch ($n_1 = n_2 = 100$, $z = -0.27$, $p = 0.79$), or density of adult conch ($n_1 = n_2 = 100$, $z = 1.75$, $p = 0.08$), but density of juvenile conch was significantly different ($n_1 = n_2 = 100$, $z = -2.38$, $p = 0.02$). Kruskal-Wallis tests showed no significant differences among habitats for the pooled data. Pair-wise comparisons of Season 1 and Season 13 for each habitat using the Mann-Whitney two-tailed test showed significant increase in total density ($n_1 = n_2 = 11$, $z = 2.22$, $p = 0.03$, Fig. 4) and density of adults ($n_1 = n_2 = 11$, $z = 2.41$, $p = 0.02$, Fig. 4) in the reef habitat, but no significant differences in those groups in any of the other habitats. There was a significant ($n_1 = 43$, $n_2 = 42$, $z = -2.91$, $p = 0.004$) difference in density of juveniles in the Seagrass habitat (Fig. 4), but no significant differences in the other habitats.

When data for Season 1 and Season 13 are sorted by map (Maps 1 to 11) and compared using the Mann-Whitney two-tailed test, there was no significant difference between the seasons in total density of conch ($n_1 = n_2 = 110$, $z = -0.44$, $p = 0.66$), or density of adults ($n_1 = n_2 = 110$, $z = 1.73$, $p = 0.08$), but density of juveniles was again significantly different ($n_1 = n_2 = 110$, $z = -2.53$, $p = 0.01$). Using Kruskal-Wallis analyses, there were significant differences among maps for total conch density ($n = 220$, $H = 25.64$, $p = 0.004$) and density of juvenile conch ($n = 220$, $H = 20.33$, $p = 0.03$), but not for density of adult conch ($n = 220$, $H = 16.54$, $p = 0.09$). Pairwise comparisons of Season 1 and Season 13 for each map using the Mann-Whitney two-tailed test showed a significant increase in total density of conch in Map 7 ($n_1 = n_2 = 10$, $Z = 1.96$, $p = 0.05$, Fig. 5) but only two other comparisons approached statistical significance, density of adults on Map 5 ($n_1 = n_2 = 10$, $Z = 1.76$, $p = 0.08$, Fig. 5) and density of juveniles on Map 8 ($n_1 = n_2 = 10$, $Z = -1.68$, $p = 0.09$, Fig. 5).

Abundance was estimated for Season 13 (Table 3) by using the stratified data. First, the sum of the average total density for each map was multiplied by the area of that map, which produced a total of 344 679 animals and a subtotal of 192 285 adults. Second, the sum of the average density for each habitat was multiplied by the area of that habitat, which gave a total abundance of 374 837 and an abundance of adults at 200 583 for Maps 1

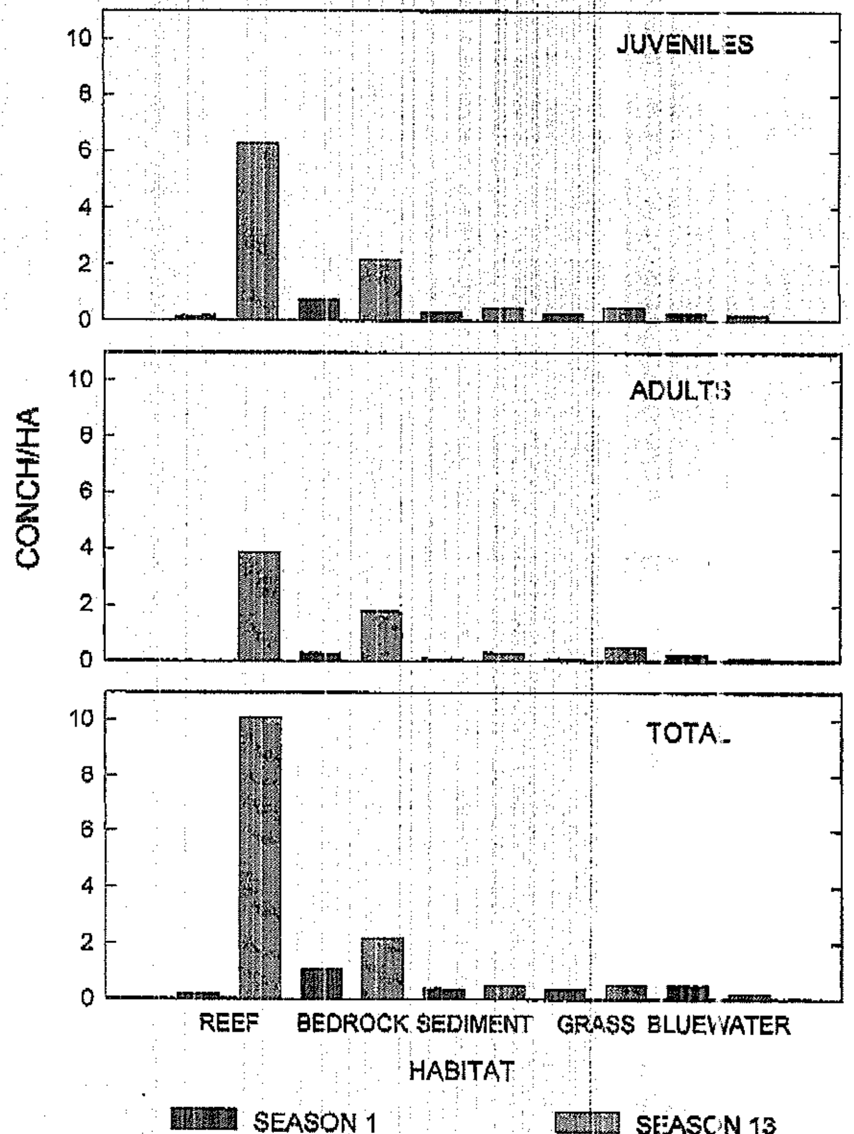


Figure 4. A comparison between Season 1 and Season 13 of average density (conch/ha) of adult conch, juvenile conch, and total conch in each of the major habitats.

to 10. These numbers were increased by 9.3% for Map 11, to become 409 697 and 219 237, respectively. Third, the overall average density for Season 13 (Maps 1 to 11) of 1.54 conch/ha was multiplied by total area, for a value of 372 474 conchs. The calculated abundance of adults at a mean density of 0.82 conch/ha is 199 319 adult conchs.

In order to improve the accuracy of our estimates of total abundance and assess the changes that have occurred during the past 13 seasons, the empirical Bayes approach was applied to the estimates of conch density. The Bayesian method is distribution-free and calculates values based upon a prior distribution. Using the empirical Bayes approach, each component value (i.e. sample mean) is calculated by treating all other prior and subsequent components as elements of the prior distribution (Maritz and Lwin, 1989). In practice, the sample values vary around a characteristic average value with, in many cases, a concurrent decrease in sample variances.

For total conch from Season 1 to Season 13 overall

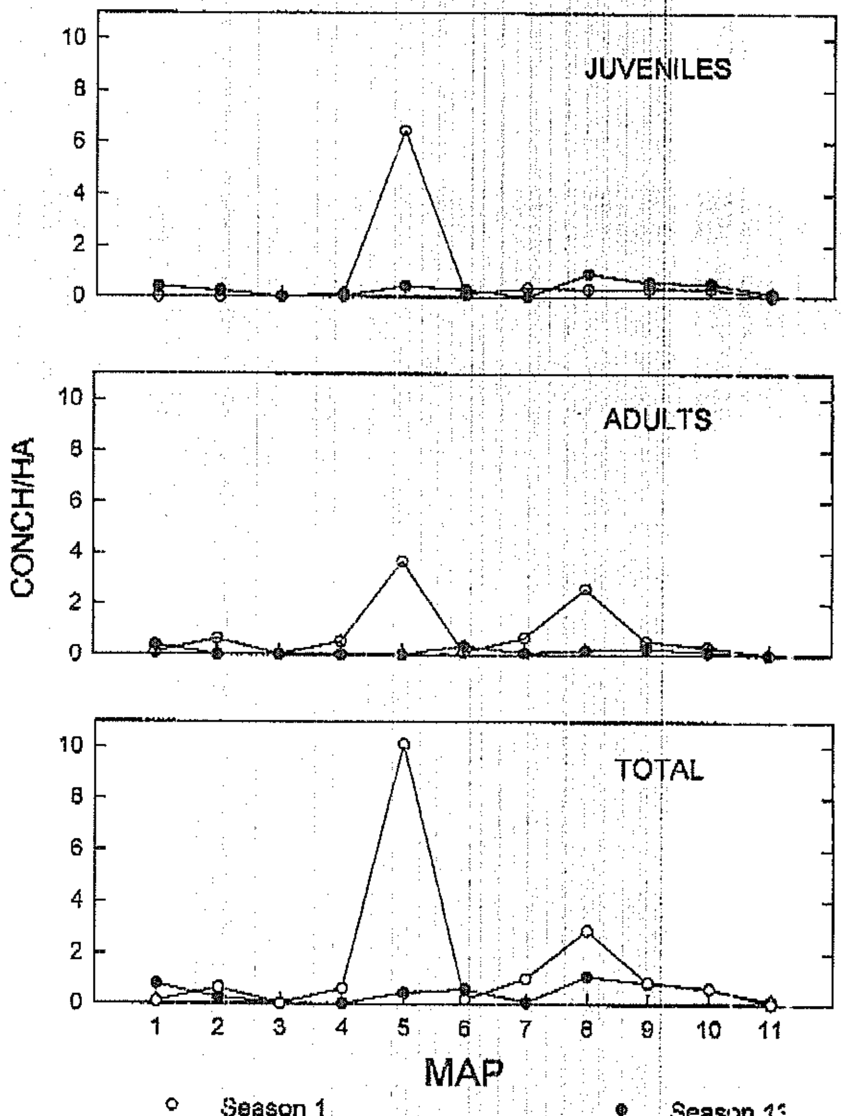


Figure 5. A comparison between Season 1 and Season 13 of average density (conch/ha) of adult conch, juvenile conch, and total conch in each of the eleven maps covering the Florida Keys. Exceptionally high values on Map 5 were caused by a single transect.

average density was calculated as 1.11 conch/ha and for adult conch it was 0.35 conch/ha. Empirical Bayes projections with 95% confidence intervals confirm that relatively little change in density has occurred over the past 13 seasons (Fig. 6) and corroborates the finding of no significant difference in total population abundance or abundance of adults between Season 1 and Season 13.

## Discussion

It is extremely difficult to assess a stock that is sparsely distributed over >200 km of coastline and that is also highly aggregated in its distribution. Although 1423 ha were surveyed in 1211 transects, which is a large sample size in comparison with most survey work, (e.g., Wood and Olsen, 1983; Smith and van Nierop, 1984; Torres Rosado, 1987; Berg *et al.*, 1992a), that total is only 0.6% of the total area. Most transects contained zero animals, but a very few contained large numbers. This produces a skewed or non-normal distribution of values, which makes it difficult to interpret the data. This difficulty was particularly evident in the comparison of densities of juveniles for Season 1 and for Season 13. Mann-Whitney analysis of ranked values showed that values for the two

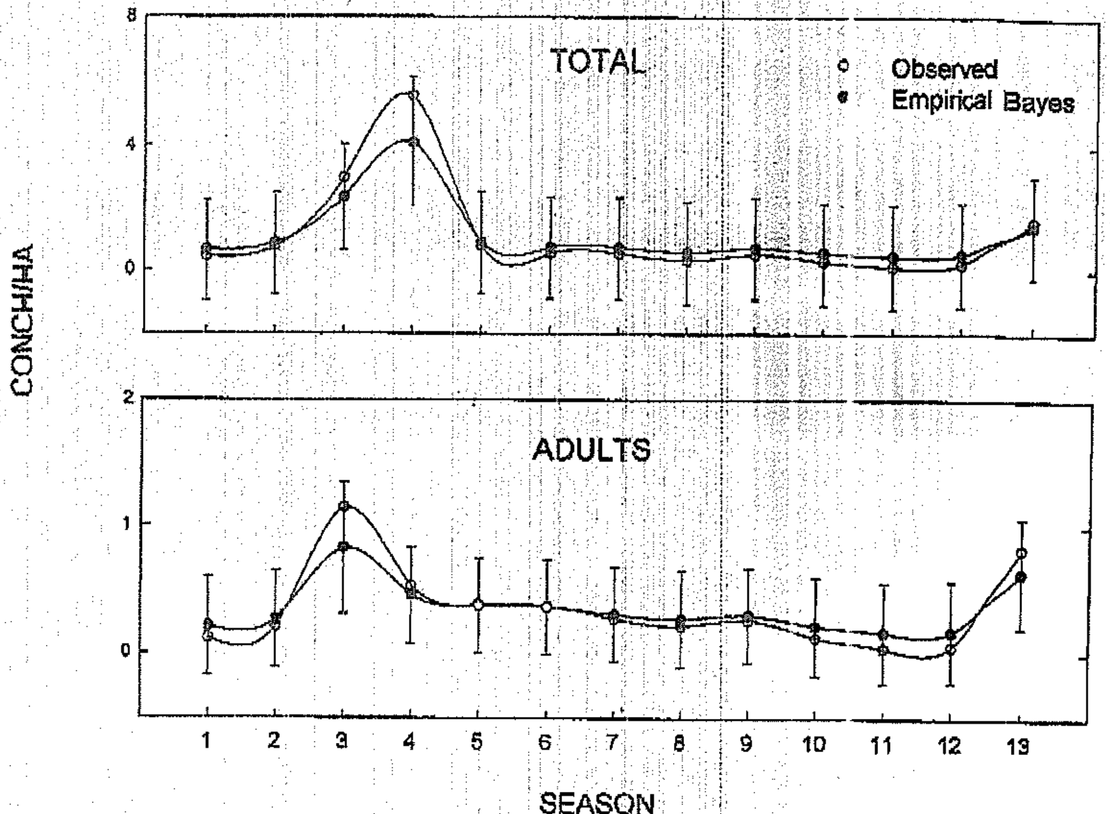


Figure 6. Empirical Bayes estimates of average density (conch/ha) and 95% confidence limits for adult conch and total conch. Observed values are seasonal average densities only.

Table 4. Average densities of *Strombus gigas* as determined by extensive surveys using towed divers.

| Location | Conch/ha | Reference |
|---|---|---|
| Bahamas | | |
| Little Bahama Bank | 28.50 | (1) |
| Great Bahama Bank | 20.79 | (1) |
| US Virgin Islands | | |
| St Thomas and St Johns | 9.70 | (2) |
| St Croix | 7.60 | (2) |
| Puerto Rico | 8.11 | (3) |
| Florida Keys | | |
| Season 1–4 | 2.40 | (4) |
| Season 13 | 1.54 | (5) |
| Bermuda | 0.52 | (6) |
| | 2.94 | (7) |

References: (1) Smith and van Nierop (1984). (2) Wood and Olsen (1983). (3) Torres Rosado (1987). (4) Berg *et al.* (1992a). (5) This study. (6) Berg *et al.* (1992b). (7) Berg *et al.* (1992c).

seasons differed significantly; the sum of ranked values for Season 13 was lowest, suggesting a decrease in the population. The median value for each season was zero; however, mean density for Season 1 was 0.33 ± 0.71 conch/ha, and for Season 13 it was 0.79 ± 6.24 conch/ha. Because of a high density (62.23 conch/ha) of animals on just one transect during Season 13, the mean value was high and the variance was large for that season. Non-parametric tests were most appropriate for distinguishing differences among samples, but they were not appropriate for descriptive statistics, because median conch density was zero in most cases.

Based on the stock monitoring transect data, empirical Bayes projections, and the comparison of densities of conch in Season 1 and Season 13, there does not appear to have been a marked increase in the abundance of conch over the study period (1987 to 1990). There is, however, a statistically significant increase in the total density of conch and the density of adult conch in the reef habitat alone. This corresponds with casual observations of local divers and fishermen. The increase may be caused by conchs aggregating at offshore sites for breeding (Berg *et al.*, 1992c), although juvenile conch were abundant at some reef habitats. Juvenile conch appeared to decrease in all other habitats, perhaps because of a combination of factors including recruitment failure, illegal collecting, habitat degradation, and mass die-offs due to extreme temperatures in shallow waters (Saltwater Fisheries Study, 1982; C. J. Berg, unpublished). Increases in the abundance of adult conch at the reef may also be due to the maturation and "stockpiling" of animals into the adult size class. Conch are juveniles for approximately 3 years before they reach maturation and the flared-lip adult stage; however, they may survive as adults for 40 years (Berg *et al.*, 1992c). A change in the percentage of adults in the population from 25.9% in Season 1 to 56.2% in Season 13, while the total number of animals remains the same, suggests animals are accumulating in the adult size class.

By using the overall average density of 1.54 conch/ha, our empirical Bayes estimate of 1.11 conch/ha, or even the maximum value of 3.84 conch/ha in the reef habitat during Season 13, we find conch are much less densely distributed in our study area than in other areas of its range where they are also protected (Table 4). Conch are not yet sufficiently abundant in Florida to sustain a fishery. We estimate that there are $2 \times 10^5$ adult conch in the Florida Keys; even if the catch was limited to one conch/person/day, the estimated 1.5 million tourists that visit annually (White, 1989) would quickly deplete the population. Also, commercial fishermen could easily collect 500 conch/day from the spotty but dense aggregations. By aggregating, conch are vulnerable to overfishing and the resource has the potential of being quickly depleted again. Therefore, it does not appear appropriate to drop the protected status of conch at this time.

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